INFILTRATION RATE (AIR LEAKAGE) IN MODERN URBAN JORDANIAN BUILDINGS IN AMMAN

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Abstract - A theoretical calculationwas deduced fromnine samples of apartments in an urban area ofwestern Amman toinvestigate the possibility of energy savingin modern buildings of construction not exceeding 20 yearsof construction age,with sliding Aluminum frame windows and similar window to floor ratio. Any excessive forced ventilation (natural or mechanical) in such dwellingsbecomes an action leading to energy losses and thermal discomfort in winter. The paper shall consider natural ventilation ratesmonitored which ranged between 0.05 ae/h to 0.18 ae/h within the framework of the mandatory minimum 4 liters of fresh natural ventilation required per second per capita for bedrooms and living areas according to the Jordanian code of energy efficient buildings 2013 and according to the Jordanian code of thermal insulation 2009, recommendation of 1-1.5 ae/h, as well as Ashrae specifications of 2.5 liters/second,as per Table 6-1, for minimum breathing rates. Analysis will be performed to evaluate energy losses through understanding the quantity of natural air leakage that occurs in Jordanian buildings and the quality of internal air in order to reach a decision over the controversial issue between architects and energy experts in Jordan over the need to ventilate homes in winter, for the sake of enhancing energy saving to recover energy lost in ventilation during winter in terms of suggesting new trends of behavior pertinent to windows and doors opening strategy (forced ventilation). This new strategy can be completely different from earlier practices used in most apartments in Jordan in order to enhance energy savings and thermal comfort.
Definition: Infiltration in used in this paper as defined in ASHRAE 2009, being an air leakage caused by a natural pressure difference from outside into the inside of a building via cracks and other unintentional openings, as well as the normal use of doors.

Key Words: Air exchange per hour (ae/h), Air leakage, Internal Air Quality (IAQ), Forced ventilation, Infiltration, Jordan National Building Council (JNBC), Mean Radiant Temperature,Natural ventilation, Relative Humidity (RH), Window to floor ratio.

I. INTRODUCTION

Various building codes and regulations were developed in order to confront the energy challenges in Jordan. Through comprehensive studies, the Royal Scientific Society has specified standards and guidelines for energy efficient practices in the Energy Efficient Building Code in 2010, followed by the Jordan Green Building Guide in 2013 (1). In addition, they developedcomputer software to simulate ventilated buildings,test air infiltrationthrough windowcracks and monitorenergy consumption from mechanical cooling[4].Hammad, M.in 2014 [5]researched green building design for a kindergarten by installing exhaust air heat recovery energy system and other green measures, which amounted to a total energy saving in cooling and heating of 61.3% denoting indirectly the high value of natural ventilation when consideringheat losses in winter. Younis, A. et al in 2017 [6] studied the health concerns of using heating devicesin low middle income families in addition to the thermal performance. It concluded thatabout 64% of the heat losses were attributed to walls and roofs, however, the research did not cover heat losses due to air infiltration and ventilation. Qawasmeh B.R. et al, in 2017 [7],calculated heating and cooling loads for single and double glazed windows in relation to the building orientation, without specifying the ventilation load.However, none of the abovementioned workshasaddressed air infiltration rates throughwindow cracksthat can cause energy losses and build up with time if not maintained efficiently. This study intends to investigate the relationshipbetween indoor air quality,infiltration rates, CO_2 concentrations, RH, noise levels and thermal comfort inside dwellings not older than 20 years. Nine cases were chosen from an overall number of 30 apartments which were studied in the statistics. The research will help understand energy losses from air infiltration through cracks in windows, openings and walls of buildings in Jordan. In addition, it will explore the indoor air quality in winter when most people close all windows and doors to keep warm. The research is conducted in Amman, the capital of Jordan.The average annual temperaturesin January are as low as 3^oC, with sub-zero temperatures on many occasions (Figure 1)[8].Furthermore, the average annual income per capita is very low ($5160) [9] according to the World

Bank statistics. In addition,the thermal quality in buildingsdoes not meet the recommended standards by the building codes.A latest outcome of a three year survey showed that only around 2% of Jordanian homes abide by building codes thermal standards [10].

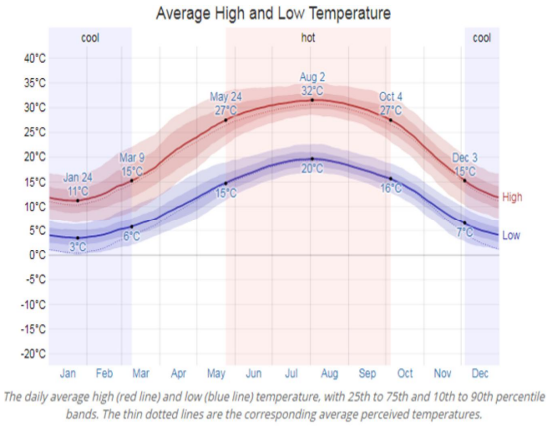


Figure (1) Amman average annual temperatures

II. METHODOLOGY

The basic principle of measurement was to calculate natural air exchange through the reduction in CO_2 when inhabitants leave their houseskeeping windows and doors closed. Wind speed was taken in consideration during the monitoring process since it is a contributing factor to the rate of air exchange in the room. In addition, allotherfactors were unified, such as the age of building, type of windows, glazing quality, opening mechanism, room orientation, exposure, wall thickness, shutters and shades, air cooling units, fans, heating systems… etc.

All windows were double glazed, aluminum frame with sliding mechanism, and window to floor ratio ranged between1:7 and 1:5. All windows had shutters on the outside and curtains on the inside which were difficult to control when taking readings. NETATMO data logger was used to monitor the readings and display them on an interactive mobile application. It was positioned on a height away from the openings. The data logger device was calibrated by leaving it outside until it had reached its lowest point on the CO_2 reading, around 4:00PM. Once calibration was complete the device was brought inside, and the windows remained closeduntil the recordings were complete, this is necessary in order to calculate the natural air exchange in the room under normal unified conditions.

III. RESULTS

Table (1) represents measurements of CO_2 at different times for case 1,as well as the value of natural infiltration rate of 0.14/hfrom points 4 and 5 represented in figure 2 at22:15 PM (point 4)on2\2\2018 till 5:15 AM on3\2\2018, while table (2) represents CO_2ppm over time when natural infiltration was taking place.

The air exchange rate λin this paper is calculated according to the equation:

$$\lambda = \text{Ln}\,[CO_2\,(A)/CO_2\,(B)]/\,[t_A - t_B] \quad \ldots \quad 1$$

Table 3 displaysthe different air exchange values per hour that resulted byusing equation (1) for cases 1-9.The calculation below is an example for points 4 & 5 as shown in table 1:

$\lambda = \text{Ln}\,(1257/473) / 7 = 0.14$ air exchange/hour (ae/h) …2

Figure (2) shows the variation of CO_2 in ppm as a function of time pertaining to case 1.However, table 2 shows CO_2 levels in addition to the relative humidity (RH %), temperature in degree centigrade and Dew Point (DP) in degree centigrade for case 9. The CO_2 fluctuation of case 9 is plotted in figure (3).

As shown in table 3 the calculated natural infiltration are at a range between 0.05 – 0.18/h for homes not older than 20 years; with an average of 0.1/h, meaning that Jordanian homes change their air naturally at an average of 2.4 times per day without opening doors or windows. A recent research done by Issam Odeh et al, in 2018 [11], calculated natural air infiltration in a Jordanian school to range between 0.3 – 4.9/h, as the natural ventilation in winter with windows closed was around 0.3/h. Another research done in 2009 by Johansson et al [12] calculated the ventilation rate in winter in a typical apartment in Amman at 0.31/h.

We note here that the differences between our findings and earlier research are high (0.3, 0.31, and 0.1) which will be discussed later.

According to the Jordanian code for energy efficient construction 2010; a minimum of 4 liters of fresh natural ventilation is required per second per capita for bedrooms and living areas. An average family of 5 in a 180 m^2 flat requires the following volume of air to be ventilated:

ae/h = 5x4x60x60 = 72 m^3/h… 3

Available natural air for 0.1 ae/h = 180x3x0.1 = 54 m^3 (3 m is the free height of ceiling)

Therefore, the correction factor of ae/h that meets the Jordanian code 2010 is:

(0.1x72/54) = 0.13 ae/h … 4

Any excess natural or mechanical ventilation exceeding that value is considered a waste of energy in winter.

If we look at table (3) of "summary of results" we find that 3 out of the 9 cases are wasting energy in winter if they used forced ventilation.However, another 3 cases (0.09, 0.09 and 0.1) are close to the target and can satisfy it if we add the effect of opening doors to natural ventilation. Therefore, only 3 cases (0.05, 0.05 and 0.07) can be considered in need of forced ventilation.

Table (1) Date and time Vs. CO_2 (High and Low) case1

KAMALIYY IN2					
Point	Time	Date	ppm	Air exchange	CO_2 generation
1	9:45	February 2, 2018	507		137 ppm /h/ person
2	13:15	Fri.	987		
3	18:15	Fri.	854		100 ppm /h/ person
4	22:15	Fri.	1257	0.14 / h	
5	5:15	Sat.	473		

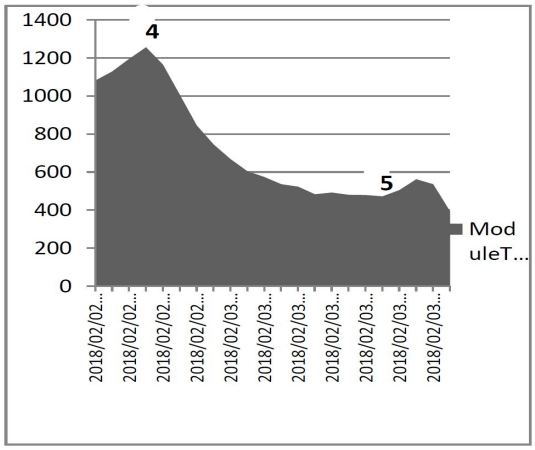


Figure (2) Co_2 particle per million (PPM) vs. time - date

Table (2) Data of case 1 on February 2-3/ 2018

Time	Temperature	Humidity	Co_2
2018/02/02 20:45:00	18.3	46	1082
2018/02/02 21:15:00	18.1	46	1130
2018/02/02 21:45:00	17.9	46	1196
2018/02/02 22:15:00	17.7	47	1257
2018/02/02 22:45:00	17.6	47	1166
2018/02/02 23:15:00	17.4	46	1007
2018/02/02 23:45:00	17.3	45	846
2018/02/03 00:15:00	17.1	45	746
2018/02/03 00:45:00	17	44	669
2018/02/03 01:15:00	16.8	44	605
2018/02/03 01:45:00	16.7	43	575
2018/02/03 02:15:00	16.6	43	537
2018/02/03 02:45:00	16.5	42	524
2018/02/03 03:15:00	16.4	42	484
2018/02/03 03:45:00	16.3	42	493
2018/02/03 04:15:00	16.3	42	481
2018/02/03 04:45:00	16.2	42	480
2018/02/03 05:15:00	16.2	42	473
2018/02/03 05:45:00	16.1	42	506
2018/02/03 06:15:00	16	43	563
2018/02/03 06:45:00	15.1	42	537
2018/02/03 07:15:00	11.6	41	394

Table (3) Summary of results: Cases of high and low readings

Case	Date	CO_2 @ A	CO_2 @ B	t_A	t_B	Air exchange	Av. Temp.	Noise dl.	Place
1	2-2-2018	1257	473	22:15	05:15	0.14	17.00	44.5	Kamaliyah
2	5-2-2018	1079	632	16:30	19:30	0.18	20.40	39.5	Weibdeh
3	5-2-2018	1000	409	00:30	09:30	0.10	19.90	38	Weibdeh
4	5-2-2018	1093	399	04:15	23:15	0.05	19.95	36.5	Weibdeh
5	6-2-2018	2187	978	01:30	10:30	0.09	21.50	NA	Weibdeh
6	6-2-2018	1046	591	00:30	11:30	0.05	20.35	36.5	Weibdeh
7	7-2-2018	1541	756	02:30	10:30	0.09	20.65	37.5	Weibdeh
8	7-2-2018	1662	665	09:05	15:05	0.15	19.85	NA	Jabal Amman
9	18-3-2018	1332	571	20:12	8:12	0.07	22.00	NA	Jabal Amman

Table (4) case 9 (Perfect Prime, CO_2, and Temp. / RH Data Logger)

Record	Time	Temp(°C)	Humidity (%RH)	DP(°C)	CO_2(PPM)
1	03-06-18 21:12:05	22.9	46.8	20.5	817
361	03-06-18 22:12:05	22.8	43.9	18	846
721	03-06-18 23:12:05	22.9	44.1	18.2	922
1081	03-07-18 00:12:05	22.9	44.9	18.9	976
1441	03-07-18 01:12:05	22.9	45.5	19.4	1008
1801	03-07-18 02:12:05	22.8	46.3	20	1081
2161	03-07-18 03:12:05	22.7	46.9	20.4	1135
2521	03-07-18 04:12:05	22.6	47.2	20.6	1180
2881	03-07-18 05:12:05	22.5	47.4	20.7	1201
3241	03-07-18 06:12:05	22.3	47.7	20.8	1258
3601	03-07-18 07:12:05	22.2	47.9	20.9	1317
3961	03-07-18 08:12:05	22.1	47.8	20.7	1332
4321	03-07-18 09:12:05	21.5	47	19.6	1099
4681	03-07-18 10:12:05	21.2	43.6	16.6	741
5041	03-07-18 11:12:05	21.1	40.5	14	550
5401	03-07-18 12:12:05	21.1	38.4	12.3	478
5761	03-07-18 13:12:05	21.2	35.9	10.3	441
6121	03-07-18 14:12:05	21.3	35	9.6	427
6481	03-07-18 15:12:05	21.5	33.6	8.6	427
6841	03-07-18 16:12:05	21.8	34.4	9.5	465
7201	03-07-18 17:12:05	21.7	32.7	8	498
7561	03-07-18 18:12:05	21.9	35.7	10.6	707
7921	03-07-18 19:12:05	22.1	38.4	13	811
8281	03-07-18 20:12:05	21.9	33.2	8.6	571
8641	03-07-18 21:12:05	21.9	33.9	9.1	571
9001	03-07-18 22:12:05	22	37.5	12.2	693
9361	03-07-18 23:12:05	22	39.6	13.9	847

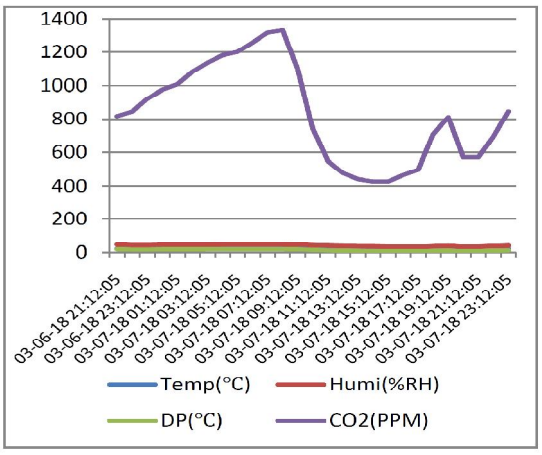


Figure (3) Case 9 CO_2 levels (6 – 7 March 2018)

CONCLUSIONS

To conclude, we can say that two thirds of cases studied (anything above O.13ae/h) showed wasted energy if forced ventilation is used in winter. If we consider the effect of opening doors alongside cracks in windows, this number will rise with time as the cracks between window frames and concrete and those between window frames themselves widen as time passes,allowingforhigher natural infiltration rates. However it should also be recognized that water vapor inducing activities inside the dwellings and their side effects were not considered in the nine samples, as heating sources were electric or central. The effect of RH ought to be considered when paraffin and gas stoves are used, particularly as many homes are poor on thermal insulation,therefore dew point dropsand the Mean Radiant Temperature (MRT) at the surface of exterior envelope drops in winter too triggering the possibility of surface condensation and fungus growth. Therefore,this holistic perspective ought to be consideredif a final decision on stopping forced ventilation is to be taken in living and sleeping quarters, excluding bath and kitchen areas that must be mechanically ventilated and confined to avoid dispersing humidity in other zones. The big difference between the outcome of ae/h compared to other research (0.31, 0.3, 0.1 ae/h) is attributed to the choice of apartments, as the smaller, older and poorer in construction quality the more natural infiltration rate becomes. We have chosen a better quality construction which might not be representative of the poorer Amman Eastern districts; but represent a substantial portion of the apartments in Western Amman.

We have also noticed that noise levels and ambient temperatures can denote a relationship with natural ventilation levels which ought to be investigated n future research.

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